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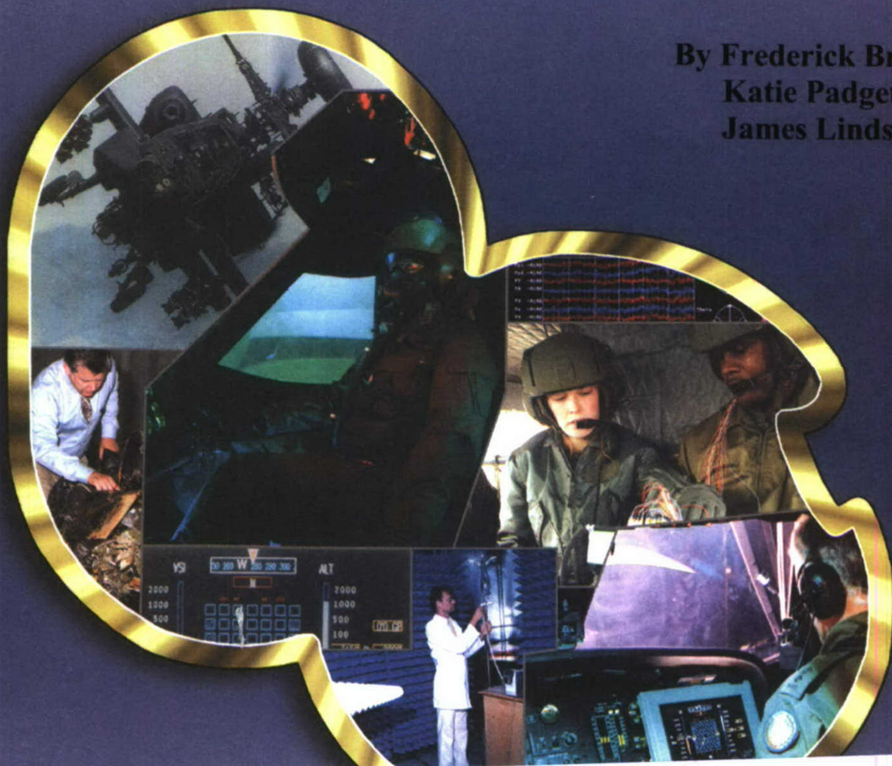
Effects of Personal Helicopter Oxygen Delivery System (PHODS) Nasal Cannula Installation on the Lateral Impact Protection of the HGU-56/P Aircrew Integrated Helmet System (AIHS)



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14. ABSTRACT

The USAARL was tasked by the Product Manager, Air Warrior, to evaluate the Aqualung Portable Helicopter Oxygen Delivery System (PHODS). The objectives were to asses the blunt impact protection and mass properties of the HGU-56/P helmets modified with the PHODS nasal cannula. Six small HGU-56/P helmets were modified with nasal cannulas and subjected to blunt eardome impacts per the HGU-56/P product specification. Mass and center of mass (CM) assessments were performed using one large HGU-56/P helmet modified with a nasal cannula. Modified HGU-56/P helmets limited headform accelerations to less than the 150-G criterion during eardome impacts. Thus, HGU-56/P helmets modified with the PHODS nasal cannula should provide adequate lateral impact protection in survivable rotary-wing mishaps. Installing the PHODS nasal cannula on the HGU-56/P flight helmet increased helmet weight and altered helmet CM position. The additional mass and change in CM did not appreciably increase the risk of sustaining acute lower neck injury for the conditions evaluated.

15. SUBJECT TERMS

Helicopter, blunt impact, helmets, HGU-56/P, Aqualung Portable Helicopter Oxygen Delivery System, PHODS, neck injury

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Background

In current U.S. Army operations, rotary-wing aircrew can be repeatedly exposed to moderately high altitude (up to 18,000 feet pressure altitude), making hypoxia and the associated performance effects a real hazard. Even at lower altitudes, supplemental oxygen can improve night vision, thereby helping to mitigate the risk of flying in the dark. The USAARL was tasked by the Product Manager Air Warrior to evaluate the Aqualung® Portable Helicopter Oxygen Delivery System (PHODS), a replacement to the continuous-flow oxygen delivery system currently in use by Army rotary-wing aviators.

The AquaLung® PHODS is man-mounted and delivers oxygen from a standard portable Survival Egress Air (SEA) bottle (located on the survival vest) via nasal cannula (figure 1). The nasal cannula is comprised of an aluminum coil (figure 2) with oxygen-carrying tubing running through its center; the aluminum coil is flexible, allowing individual users to position the cannula without kinking the interior tubing.

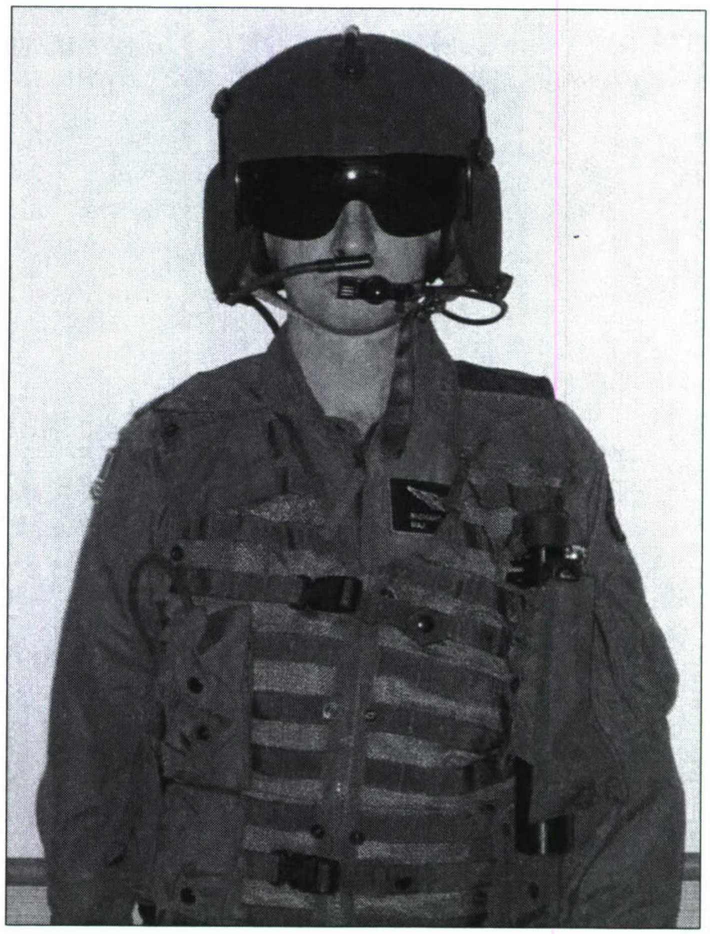

Figure 1. Aqualung® PHODS in typical aviation configuration.

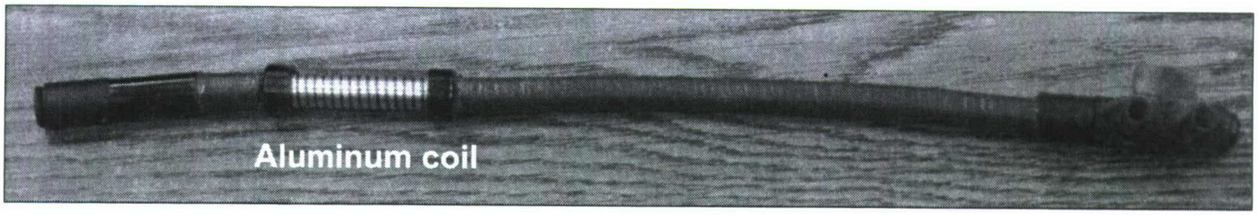

Figure 2. PHODS Nasal cannula.

A unique feature of this system is the inclusion of a MH EDS 02D1 Pulse Demand Oxygen Unit that automatically provides on-demand oxygen regulated to altitude based on barometric pressure (pressure altitude). Other features of the regulator include algorithms to detect and react to the aviator's breathing patterns.

All portions of the PHODS are mounted to the survival vest except the nasal cannula, which mounts to the lower, interior edge of the eardome region of the HGU-56/P flight helmet (figure 3). In this position, the cannula could interfere with placement of the energy-absorbing crushable earcups installed in the HGU-56/P, possibly compromising the crashworthiness of the earcup.

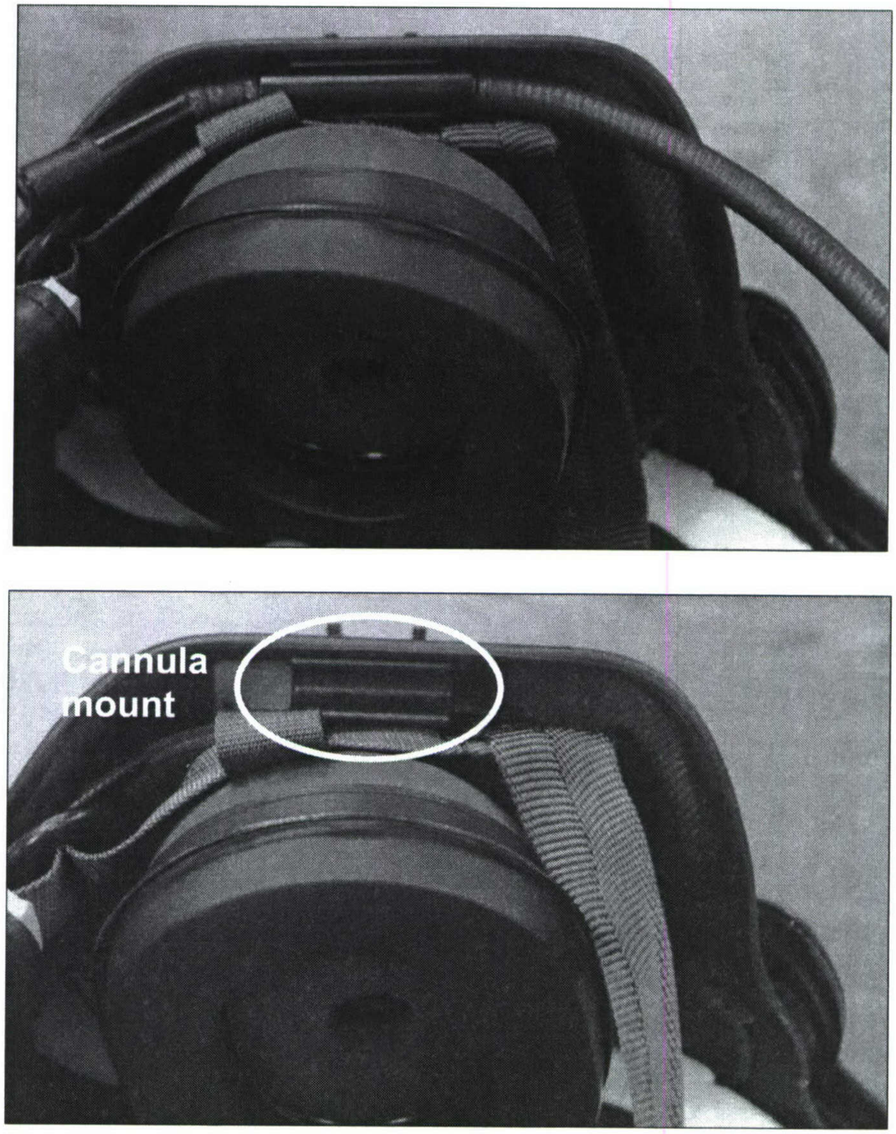

Figure 3. Nasal cannula mounting in the HGU-56/P flight helmet. An HGU-56/P is shown with (top) and without (bottom) the nasal cannula installed.

A recent USAARL laboratory assessment demonstrated the feasibility of employing the PHODS for use during high-altitude rotary-wing flight operations (Curry and Roller, 2007). As such, the PM-Air Warrior (PM-AW) is continuing the process of qualifying the PHODS for Army-wide use. As part of that process, the PM-AW asked the USAARL to assess the blunt impact head protection provided by a HGU-56/P flight helmet when configured with the PHODS nasal cannula. In addition, PM-AW asked that USAARL determine the effect of mounting the PHODS cannula to the HGU-56/P on the mass and center of mass of the helmet system.

Military relevance

Adams, et al. (in press) have completed a retrospective study of HGU-56/P performance between 1996 and 2004. Seventy (70) helmets from 31 rotary-wing accidents were examined in conjunction with the accident and injury reports. Of the 70 helmets, 50 were involved in survivable rotary-wing mishaps. Of the 50 individuals, greater than 50 percent (n = 28) sustained no head injury. With the exception of one, the remaining head injuries were limited to mild concussions. The worst head injury sustained during a survivable crash event was a brain contusion. Of the 22 individuals sustaining some type of head injury during a survivable crash, none lost consciousness (Adams, et al.; in press). This retrospective analysis of HGU-56/P helmets has demonstrated the ability of the standard HGU-56/P helmet to protect the wearer from severe head injury.

The primary reason for the success of the HGU-56/P is the stringent blunt impact protection requirements imposed on its design. The HGU-56/P is designed to provide conscious survivability in severe, but survivable rotary-wing mishaps. To achieve this, the helmet is designed to limit head accelerations to 175 Gs or less when impacted in the headband region at 6.0 meters per second (mps). The Army has recognized 175 Gs to be the threshold for consciousness (Slobodnik, 1980). To protect against basilar skull fracture, the HGU-56/P is designed to limit head accelerations to 150 Gs when impacted at 4.0 mps in the crown or at 6.0 mps on the eardomes (Department of Defense, 1996).

The use of helmet mounted devices increases the head-borne weight and changes the helmet's mass moments of inertia. During crash events, acute neck injury could result from improperly weighted helmets. Extended missions and continuous operations with improperly weighted helmets induce neck fatigue, which can degrade aircrew performance and potentially introduce chronic neck injury.

Any modifications to the standard HGU-56/P helmet may negatively affect the crashworthiness of the helmet. Therefore, any modifications to the standard HGU-56/P helmet is stringently evaluated to ensure the protection provided to the aviation warfighter is not compromised.

Objectives

The primary objective of this study was to assess the blunt impact head protection provided by the HGU-56/P flight helmet when configured with the PHODS nasal cannula. A secondary objective was to determine the effects of mounting the PHODS nasal cannula on the weight and location of the center of mass (CM) of the helmet.

Materials and methods

Experimental equipment

Helmets

Six (6) lightweight HGU-56/P flight helmets were provided by PM-AW for the blunt impact evaluation. All helmets were small size. Nasal cannula mounts were installed on the left and right eardomes of each helmet. This allowed two eardome impacts to be conducted on each helmet. (In the fielded system, the nasal cannula will be mounted to the right eardome.) Microphone booms were removed from the left eardome of each helmet to allow the installation of the cannula mount. For these tests, Communication Enhancement and Protection System (CEPS) volume controls were mounted to the exterior of the helmet shells using the cannula mounting screws. This is the intended mounting location of the CEPS volume control in helmets equipped with the CEPS. Cannula mounts and CEPS controls were installed by USAARL personnel using the template and installation procedures provided in appendix B.

Large HGU-56/P flight helmets were used for mass properties measurements. A PHODS cannula mount was installed on the right eardome of one helmet. A second large HGU-56/P flight helmet was left unmodified, as a control helmet.

Monorail drop tower

Blunt impact attenuation tests were performed on a guided, free fall drop tower (figure 4) conforming to FMVSS 218 (Department of Transportation, 1992). As only the earcup regions of the helmet were tested, a modified DOT size C headform was used for all impact tests. The modified headform had flanges along the left and right sides, allowing greater contact area between the helmet's earcup and headform. The total weight of the drop arm assembly and of the headform was between 11.0 and 11.44 pounds (lbs). The modified medium headform is shown in figure 5. Physical dimensions for the modified medium headform are provided in figure 6.

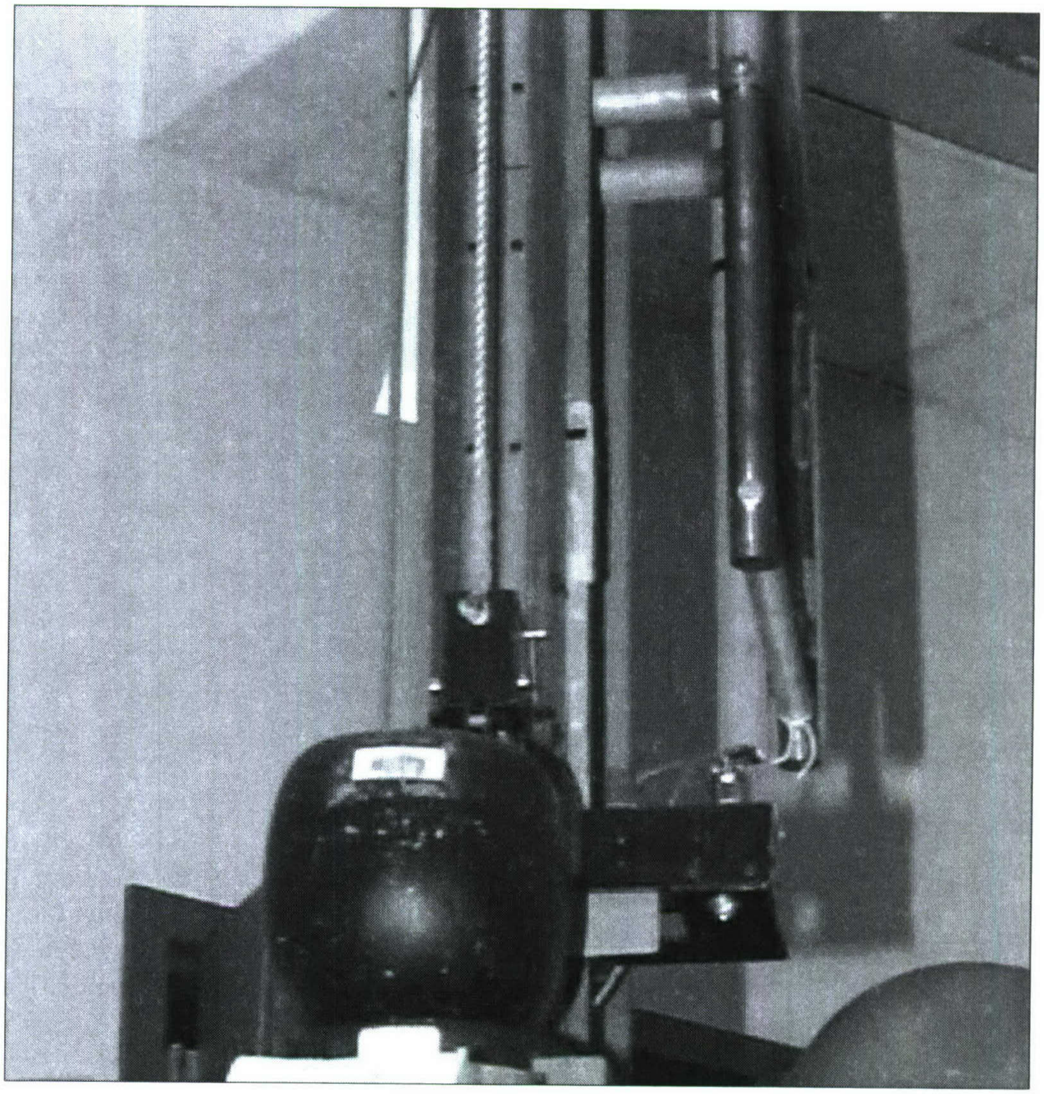

Figure 4. Guided, free fall drop tower (shown with the standard medium headform installed).

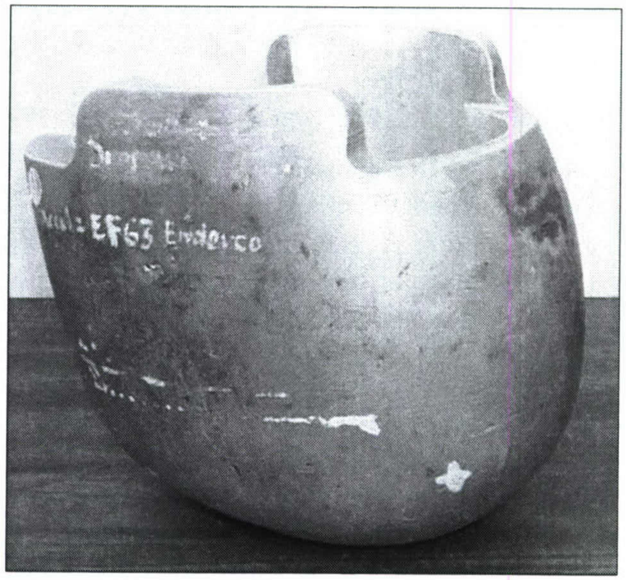

Figure 5. The modified medium size headform.

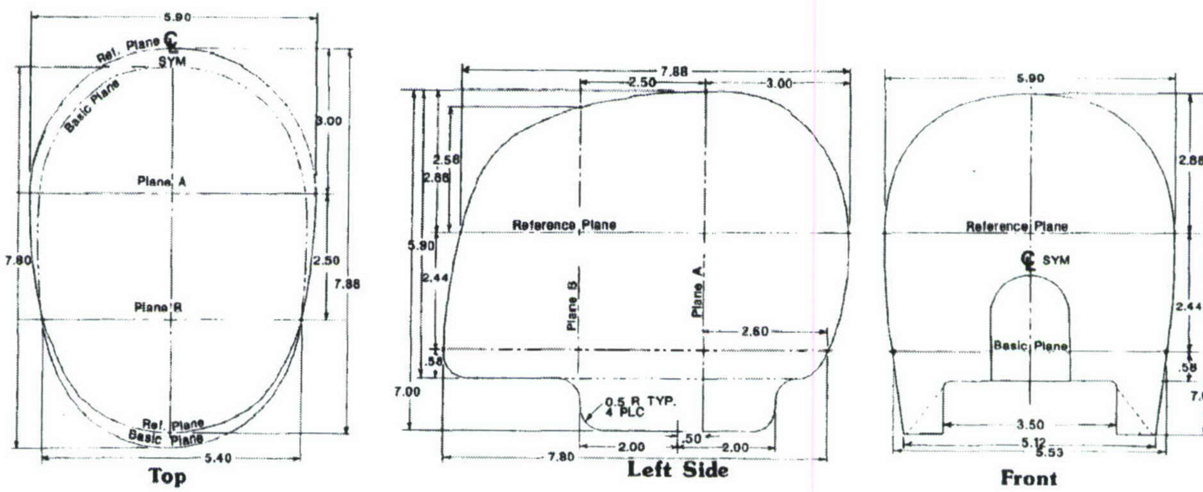

Figure 6. Modified medium headform dimensions. All dimensions are in inches.

Three channels of data were collected during blunt impact tests. A single-axis, linear accelerometer (Endevco model 2221D) installed in the center of mass of the headform measured vertical deceleration of the headform at impact. Impact force was measured using three load washers (Kiagg-Swiss model 902A) installed beneath the impact anvil. The velocity sensor (GHI

Systems model VS300 Velocimeter) output voltage, which triggered the data acquisition system, was also recorded. Data were recorded at 10,000 samples per second per channel.

Mass properties instrument

Mass properties measurements, CM and mass moments of inertia (MOI), were made using a KSR330-60 mass properties instrument (MPI) manufactured by Space Electronics, Inc. (figure 7). CM was calculated using a summation of moments about the test platform's pivot axis (the pivot axis serves as the fulcrum for the test platform, which is suspended by a rotary gas bearing). The force required to balance a test part on the test platform's pivot axis was measured using a force transducer located a known distance from the pivot axis. The distance between the part's CM and the pivot axis was calculated using the measured force, the known distance between the force transducer and platform pivot axis, and the mass of the part (measured using a simple scale prior to testing). MOI was calculated based on the period of rotational oscillation of the test platform, which is configured as an inverted rotary pendulum (Deavers & McEntire, 1996). MPI operation and data collection were automated using a Microsoft™ Windows 98 workstation.

Figure 7. KSR330-60 Mass properties instrument.

A USAARL mid-size (50^{th} percentile) male headform was mounted to the MPI test platform. The headform could be oriented along three orthogonal planes: XY, XZ, and YZ. The origin and axis for these headform orientations were coincident with the head anatomical coordinate system (figure 8). The orientations were named based on the axes along which the CM positions were being measured. For example, the headform in figure 7 is oriented in the XY orientation. In this orientation, the anterior-posterior (X) and lateral (Y) CM positions of the helmet are measured. In each orientation, the vertical centerline of the test platform intersected the headform at the tragion notch – the center of mass of the mid-size male head and neck combination. Thus, all CM measurements made using the USAARL headform were relative to the mid-size male head and neck center of mass.

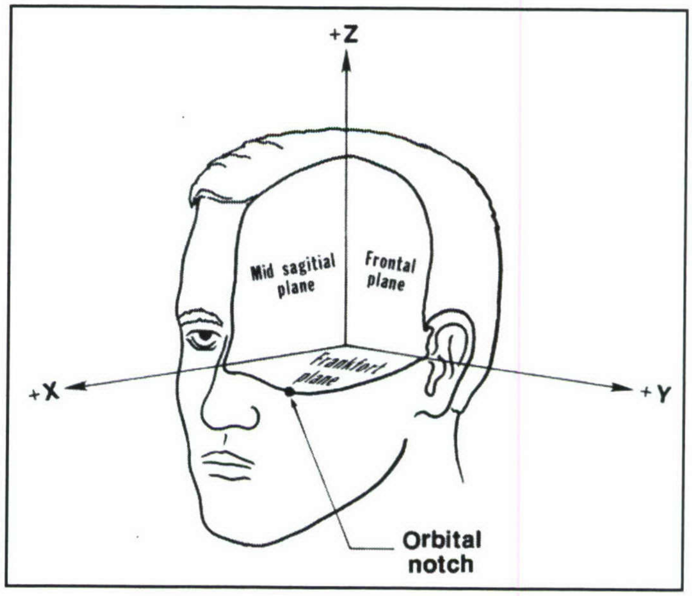

Figure 8. The head anatomical coordinate system.

Experimental methods

Blunt impact protection

The six small helmets were divided into two groups of three helmets. One group was tested at ambient temperature (70 ± 5 °F), while the second group was pre-conditioned at 122 ± 5 °F for at least 4 hours prior to testing (Department of Transportation, 1992). Each helmet was impacted once on each eardome at a target impact velocity of 19.7 feet per second (fps) (Department of Defense, 1996). All impact tests were conducted with nasal cannulas mounted to the HGU-56/P helmet.

Blunt impact evaluations were conducted as specified in the HGU-56/P purchase description (Department of Defense, 1996) with two exceptions. First, only the eardome areas of each helmet were subjected to blunt impacts. The remaining impact sites specified in the HGU-56/P purchase description document – front, rear, crown, left headband, and right headband – were not used. Second, although not required by the HGU-56/P purchase description, three helmets were subjected to blunt impact testing after conditioning at 122 °F for 4 hours. The HGU-56/P is being worn in cockpits with consistent interior temperatures above 120 °F. For this reason, it was believed prudent to assess the lateral impact protection of the modified helmet at elevated temperatures.

Helmets were mounted to the headform. The helmet chin and nape straps were adjusted to achieve a snug fit; helmets were not allowed to fit loosely or droop from the headform. The combined helmet/headform assembly was raised to the drop height necessary to achieve the desired impact velocity and released. The helmet/headform assembly impacted a flat steel anvil at the base of the drop tower.

Helmet impact velocity, headform impact acceleration, and impact force were recorded during each test. The impact force was recorded for informational purposes only. After each test, each helmet was thoroughly inspected for loose components and distorted hardware. Also, test headform orientation was checked and adjusted if necessary.

Mass properties

The large HGU-56/P helmets were fitted onto the test headform (figure 7). During CM measuring, the helmeted headform was positioned orthogonally in three orientations: XY, XZ, and YZ. A minimum of three measurements were made in each headform orientation with the helmet being removed and replaced between measurements. The multiple helmet removals and repositioning are conducted in an attempt to replicate minute, natural variations in the aviator helmet position that occur between repeated helmet donning and doffing cycles. The results for each axis were averaged to obtain the overall result.

Three configurations of HGU-56/P flight helmet were measured and their mass properties recorded. These configurations included:

- one large HGU-56/P with no additional equipment,
- one large HGU-56/P with the PHODS cannula mount installed, and
- one large HGU-56/P with the PHODS cannula mount and cannula installed.

Data analysis

Blunt impact protection

The headform accelerations were filtered at CFC 1000 according to SAE J211 (Society of Automotive Engineers, 1995) and the peak acceleration values were recorded for each helmet impact. Peak headform accelerations were compared to the 150-G pass-fail criterion for HGU-56/P

earcup impacts as specified in the HGU-56/P purchase specification (Department of Defense, 1996). Any peak headform accelerations greater than 150 Gs would indicate that the modified HGU-56/P flight helmets offer less blunt impact protection than the standard HGU-56/P.

Peak headform accelerations measured during this evaluation were compared to historical HGU-56/P lot acceptance test data. This comparison was conducted to determine if the addition of the PHODS nasal cannula mount and nasal cannula caused a statistically significant difference in lateral impact protection. The t-test was designed to identify a statistically significant difference between the two groups with 80 percent accuracy (a power of 0.80) and a probability of Type I error of five percent ($\alpha = 0.05$).

Additionally, a two-factor analysis of variance (ANOVA) was used to determine the influence of impact site and helmet temperature on peak headform acceleration. SigmaStat for Windows version 3.10 (Systat Software, Inc., San Jose, CA) was used to perform the calculations. As with the t-test, the ANOVA was designed to identify statistically significant differences with a power of 0.80, assuming an α of 0.05.

Mass properties

The Swedish Royal Institute of Technology (KTH) has developed a validated, biofidelic finite element model of the human neck (Haldin, et al., 2005). The KTH neck model can predict forces and moments acting on vertebral bodies, neck ligament strain, and stresses in the vertebrae and the intervertebral discs. As it is a mathematical model, additional head-supported mass can be added to the model at specific CM locations. This allows parametric studies of the effect of HSM and CM position on neck loads, ligament strain, etc.

The USAARL contracted with the KTH to conduct a series of simulations using this model. The purpose was to evaluate the influence of HSM and CM placement on the risk of acute neck injury during severe, but survivable dynamic impacts. The following parameters were included in the simulation runs (Haldin, et al., 2005).

- Head-supported masses of 1, 2, and 3 kilograms (kg)
- Longitudinal CM positions of -2, 0, 2, 4, and 6 centimeters (cm) (relative to the head CM)
- Vertical CM positions of -2, 0, 2, 4, and 6 cm (relative to the head CM)
- Three impact acceleration levels (5, 13.5, and 22 Gs)
- Seven impact conditions – pure +Gx (forward), pure –Gx (rearward); pure +Gz (vertical), pure lateral (+Gy), combined longitudinal-vertical (Gxz), combined lateral-longitudinal (Gxy), and combined lateral-vertical (Gyz)

Forces and moments acting on the base of the neck (the junction of the seventh cervical and first thoracic [C7/T1] vertebrae) were computed for each combination of mass, longitudinal CM position, vertical CM position, impact condition, and impact acceleration. In turn, these data were used to calculate a corresponding Beam Criterion value (Bass et al, 2004). Bass, et al. (2004) also

showed that the risk of incurring an Abbreviated Injury Scale (AIS) 2 lower neck injury increases logarithmically as Beam Criterion values increases (Equation). Lower neck injuries classified as AIS 2 include:

- intervertebral disc herniation without nerve root damage,
- dislocation of one vertebra relative to another without vertebral body fracture or spinal cord contusion or laceration,
- vertebral fracture without spinal cord contusion or laceration or without dislocation (including burst fractures resulting in less than 20 percent loss of vertebral height),
- laceration of the interspinous ligament,
- contusions to or a single laceration of or a single avulsion of the nerve root, and
- acute strain not resulting in fracture or dislocation.

$$Risk(BC) = \frac{1}{1 + \exp\left[\frac{1 - BC}{0.19}\right]} \qquad \text{(Equation)}$$

The mass, longitudinal CM positions, and vertical CM positions used in the simulations did not match those measured during this evaluation of the HGU-56/P flight helmet. Therefore, for each combination of impact condition and impact acceleration, the Beam Criterion values resulting from the simulations were input into a multiple linear regression model. The resulting equations predicted Beam Criterion values as a function of HSM, longitudinal CM position, and lateral CM position. The mass properties of the various HGU-56/P helmets in the equipment configurations mentioned above were input into these regression equations to determine each helmet configuration's Beam Criterion value. In turn, these Beam Criterion values were input into the Equation to compute a corresponding risk of AIS 2 injury.

Additionally, the USAARL has conducted several in-house studies investigating the effects of HSM and longitudinal CM position on Soldier fatigue and performance. These studies showed that HSM and longitudinal CM position had statistically significant effects on Soldier performance in visual tracking tasks and perceptions of helmet comfort and flight difficulty (Alem & Meyer, 1995; Alem & Fraser, 2006; Fraser, Alem, & Chancey, 2006). Comparisons between the HSM and CM positions tested during these studies and those measured during the present evaluation can be made to provide qualitative insight into possible performance decrements.

Results and discussion

Blunt impact protection

Peak headform accelerations were recorded for each helmet impact (table 1). For four impacts, the impact velocity exceeded 19.70 fps as specified in FNS PD 96-18 (Department of Defense, 1996) for eardome impacts. However, all impacts resulted in peak headform accelerations below the 150 G earcup pass-fail criterion. No statistically significant correlation was found between the

recorded impact velocities and peak headform acceleration (Pearson Product Moment Correlation, p = 0.598).

Table 1.
Eardome impact data.

Eardome	Environment	Impact velocity (fps)	Peak headform acceleration (G)
Right	Ambient	19.50	129.0
		19.72	117.6
		19.72	132.4
	Hot	19.47	118.3
		19.75	113.4
		19.65	101.0
Left	Ambient	19.26	112.6
		19.77	108.7
		19.53	109.4
	Hot	19.62	109.2
		19.29	105.7
		19.69	120.6

Inspection of table 1 indicates that impacts to the right eardome resulted in higher peak head accelerations than did impacts to the left eardome. The average impact acceleration measured for all right and left eardome impacts were 118.6 G (± 11.3 G) and 111.0 G (± 5.2 G), respectively. However, table 2 shows that neither impact site (p = 0.104) nor helmet temperature (p = 0.132) had a significant effect on the peak headform accelerations measured during these trials. An explanation as to why right eardome impacts appear to have resulted in higher peak headform accelerations is not immediately apparent, as test procedures and instrumentation did not change between impact sites, impact velocity had no statistically significant effect on peak headform accelerations, and the HGU-56/P is designed and constructed to be symmetric about the mid-sagital plane.

Table 2.
Two factor ANOVA analysis of the influence of temperature and impact site on peak headform acceleration.

Source	Degrees of freedom	Sum Sq.	Mean Sq.	*F*	*p*
Temperature	1	143.52	143.52	2.81	0.132
Impact site	1	172.52	172.52	3.37	0.104
Temperature × Impact site	1	217.60	217.60	4.25	0.073
Error	8	409.26	51.16		
Total	11	942.90	85.72		

Peak headform accelerations measured during these trials (table 1) were found to be statistically lower ($p < 0.001$) than those measured during HGU-56/P lot acceptance tests. The average peak headform acceleration measured during this evaluation was 118.3 G (±10.2 G), while the average peak headform acceleration for the lot test data was 139.8 G (±9.1 G). Per the HGU-56/P production specification, only helmets conditioned at ambient laboratory temperature are subjected to eardome impacts (Department of Defense, 1996). Thus, data from eardome impacts to helmets conditioned at 122°F were excluded from the comparison. Lot acceptance tests were conducted on medium and large HGU-56/P flight helmets. No statistical difference was found between the two helmet sizes (t-test, $p = 0.055$); therefore, data from the two helmet sizes were grouped and compared to peak headform accelerations measured during this evaluation. For both data sets, peak headform accelerations measured during left and right side eardome impacts were combined.

In the late 1970's, analysis of damaged rotary-wing helmets by the USAARL Aviation Life Support Equipment Retrieval Program (ALSERP) revealed a need for crashworthy earcups (Shanahan, 1983). ALSERP investigators noted a large number of fatal basilar skull fractures occurring in survivable Army rotary-wing mishaps. Analysis of the helmets involved in these mishaps showed evidence of lateral impacts to the helmet (damage to exterior eardome region of the helmet) without concurrent damage to the sound attenuating earcup. Subsequent testing of the SPH-4 earcup demonstrated that more than 5000 lbs of compressive force was needed to crush these earcups (Hundley & Haley, 1984). A concurrent review of the literature revealed that basilar skull fractures could occur at forces as low as 1500 lbs (Travis, Stalnaker, & Melvin, 1977). Given the difference between the compressive strength of the earcups and the base of the skull, it was evident that the non-crashworthy earcups allowed the energy from lateral impacts to be transferred directly to the wearer's skull, elucidating the need for crashworthy energy-absorbing earcups in rotary-wing helmets.

Installation of the PHODS nasal cannula mount to the lower edge of the HGU-56/P eardome does not appear to degrade the lateral impact protection of the helmet. Peak headform accelerations (table 1) remained below the pass-fail criterion of 150 Gs for lateral impacts to the HGU-56/P AIHS (Department of Defense, 1996). The modified HGU-56/P flight helmets should provide the same lateral blunt impact protection than the standard HGU-56/P.

Mass properties

The mass, average CM locations measured along the longitudinal (anterior-posterior), lateral (left-right), and vertical axes, and weight moments for the three configurations of large HGU-56/P flight helmets evaluated are presented in table 3. All CM locations were measured relative to the tragion notch; the weight moments represent the pitching moment about the lateral axis (the axis running from left ear to right ear through the tragion notch).

Table 3.
Mass and CM positions.

Equipment configuration	Mass (kg)	X-axis (mm)	Y-axis (mm)	Z-axis (mm)	Weight moment (N-cm)
Large HGU-56/P, no additional equipment (helmet only)	1.377	7.887	6.057	44.072	10.65
Large HGU-56/P w/cannula mount (no cannula installed)	1.403	9.702	3.007	45.732	13.35
Large HGU-56/P w/cannula mount and cannula installed	1.464	8.659	0.270	38.087	12.44

As expected, the mass of the large HGU-56/P flight helmets increased as additional equipment (i.e., the PHODS cannula mount and PHODS cannula) was added to the helmet (table 3). Addition of the PHODS cannula caused the CM of the large HGU-56/P to shift forward (represented by an increase in X-axis CM position as compared to the unmodified helmet) and downward (indicated by a reduction in Z-axis CM position). Installation of the PHODS cannula also resulted in the helmet becoming more balanced about the mid-sagittal plane (indicated by the Y-axis CM position tending toward a value of 0), as the mass of the PHODS cannula offsets the mass of the microphone boom mounted to the opposite eardome.

Acute injury

Mass and CM position data for each large HGU-56/P flight helmet configuration (table 3) were used to compute Beam Criterion values and AIS 2 lower neck injury risks for the 5-, 13.5-, and 22-G impact accelerations and the vertical (+Gz), longitudinal (-Gx), and combined longitudinal-vertical (Gxz) impact conditions (table 4). The combined Gxz impact condition proved to be the worst case impact condition, as simulations involving this impact condition resulted in the highest Beam Criterion values and injury risks. As the worst case condition, all injury risk assessments were based on the combined Gxz impact condition.

Table 4 shows a consistent trend across the three HGU-56/P configurations. Beam Criterion values and injury risk increases with increased impact acceleration levels, for a given equipment configuration (table 4). This trend makes sense, since greater impact accelerations would result in higher inertial loading of the neck. While only results for the combined Gxz impact condition are presented, this trend held true for all combinations of impact conditions and impact accelerations.

Table 4.
Predicted Beam Criterion values and associated injury risks for each large HGU-56/P equipment configuration based on the combined longitudinal-vertical (Gxz) impact condition.

Equipment configuration	Beam Criterion values			AIS 2 injury risk (percent)		
	5-G	13.5-G	22-G	5-G	13.5-G	22-G
Large HGU-56/P, no additional equipment (helmet only)	0.24	0.73	1.15	1.77	19.58	69.24
Large HGU-56/P w/cannula mount (no cannula installed)	0.24	0.73	1.16	1.79	19.83	69.74
Large HGU-56/P w/cannula mount and cannula installed	0.24	0.73	1.18	1.78	19.80	72.15

The addition of the PHODS cannula mount and cannula tube had little impact on the risk of acute neck injury. For the worst-case, Gxz impact condition, the Beam Criterion values and their corresponding injury risks remained almost constant for the three large HGU-56/P configurations with the largest increase in injury risk being slightly less than 3 percent.

The AIS classifications are based on the likelihood of an injury resulting in death. AIS classifications range from 1 to 6, with an AIS 6 injury being unsurvivable. AIS 2 injuries, like those the Beam Criterion is intended to predict, are considered moderate and do not involve the spinal cord. Therefore, in normal, healthy individuals, such as Army aviation crewmembers, AIS 2 injuries are non-fatal and not life-threatening. Also, injuries of this nature are not disabling and would be unlikely to hinder a crewmember's ability to egress an aircraft.

Performance implications

The masses and longitudinal CM positions of the large HGU-56/P helmet configurations are presented in figure 9. The solid black curve shown in each figure represents a constant 78 Newton-centimeter (N-cm) weight moment about the tragion notch. The large black squares represent combinations of HSM and longitudinal CM position tested by Alem and Frasier (2006) during studies of aviator flight performance and vigilance during 1.5-hour sorties in the USAARL NUH-60 research flight simulator. The numbers in bold above each black square represent its corresponding weight moment relative to the tragion notch.

Alem and Meyer (1995) subjected volunteer subjects to 4-hour simulated helicopter rides with varying combinations of HSM and longitudinal CM position. During each 4-hour session, subjects were asked to track moving targets. The amount of time necessary to acquire the targets and extinguish them (by holding a laser on the target for about 1 second) was recorded. Analysis showed that subjects' abilities to consistently track a moving target degraded (the amount of time needed to acquire and extinguish the target increased) at weight moments above 78 N-cm.

Alem and Fraser (2006) found a similar effect during volunteer studies in the NUH-60 flight simulator. Target acquisition time was found to increase as weight moment increased. While Alem and Fraser (2006) did not identify a critical weight moment value, they did show that HSM had a

significant effect on target acquisition time, with greater HSM corresponding to increased acquisition time.

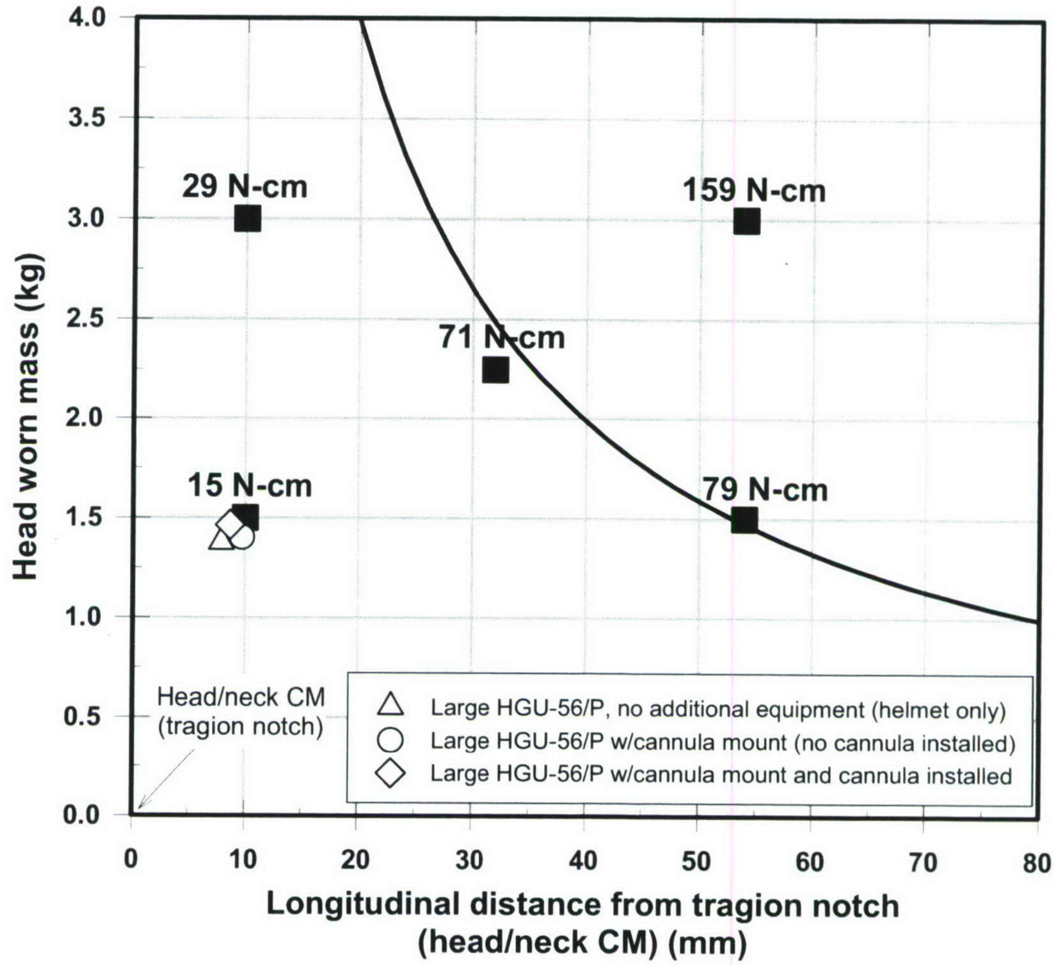

Figure 9. Mass and longitudinal CM position of large HGU-56/P helmets in various equipment configurations. The solid black line represents a constant weight moment of 78 N-cm about the tragion notch. The five large, solid black squares represent combinations of HSM and longitudinal CM position tested by Alem and Frasier (2006) during studies of pilot performance.

The three combinations of large HGU-56/P helmets evaluated during this study have similar weight moments (table 3). In addition, figure 9 shows that each large HGU-56/P helmet configuration fell below the 78 N-cm curve. Based on the two studies described above, it can be inferred that aviators wearing HGU-56/P helmets equipped with the PHODS cannula mount and nasal cannula will take about the same time to acquire and identify targets (e.g., other aircraft, ground-based threats) as those flying with an unmodified HGU-56/P helmet.

Study limitations

Although small-size HGU-56/P flight helmets were used during the blunt impact evaluation, the construction of the eardome regions of the HGU-56/P helmet shell is consistent between helmet shell sizes. The impact attenuation data gathered should provide insight into the performance of other HGU-56/P helmet sizes modified in the same manner as those used during this evaluation.

The linear regression models used to calculate Beam Criterion values are based on the results of finite element simulations whose input parameters were described previously. (Beam Criterion values were subsequently used to predict AIS 2 lower neck injury risk using the Equation.) The input parameters did not include all conceivable impact orientations and acceleration levels. These results should not be extrapolated to determine injury risks for impact orientations and acceleration levels other than those described previously.

Conclusions

When modified with the PHODS nasal cannula mount and cannula, the HGU-56/P flight helmet limits headform accelerations to less than the 150-G criterion during specified lateral eardome impacts whether tested at ambient or hot temperatures. As such, HGU-56/P flight helmets modified with the PHODS nasal cannula mount and cannula should provide adequate lateral impact protection in survivable rotary-wing mishaps.

Installing the PHODS nasal cannula mount and cannula on the HGU-56/P flight helmet increases helmet weight and alters the position of the helmet CM relative to the tragion notch when compared to an unmodified helmet. However, the additional mass and change in CM did not appreciably increase the risk of sustaining acute lower neck injury at the acceleration levels and impact orientations described herein. In addition, installation of the PHODS nasal cannula mount and cannula should not adversely affect the wearer's ability to identify and track targets.

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Appendix A.

List of manufacturers.

AquaLung
2340 Cousteau Court
Vista, CA 92081

Gentex Corporation
P.O. Box 315
Carbondale, PA 18407

Space Electronics, Inc.
81 Fuller Way
Berlin, CT 06037

Systat Software, Inc.
1735 Technology Drive
Suite 430
San Jose, CA 95110

Appendix B.

PHODS cannula mounting template and procedures.

1. Print out template (figure 10).

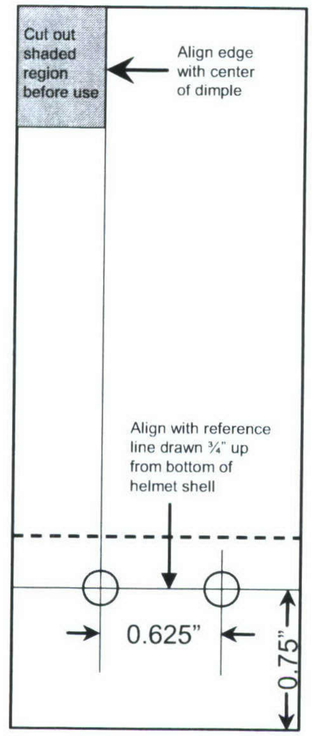

Figure 10. PHODS cannula mounting template.

2. Cut shaded region out of template. Set template aside.

3. On the right eardome, measure ¾ inches up from the edge of the helmet shell in two places and connect with a line (figure 11).

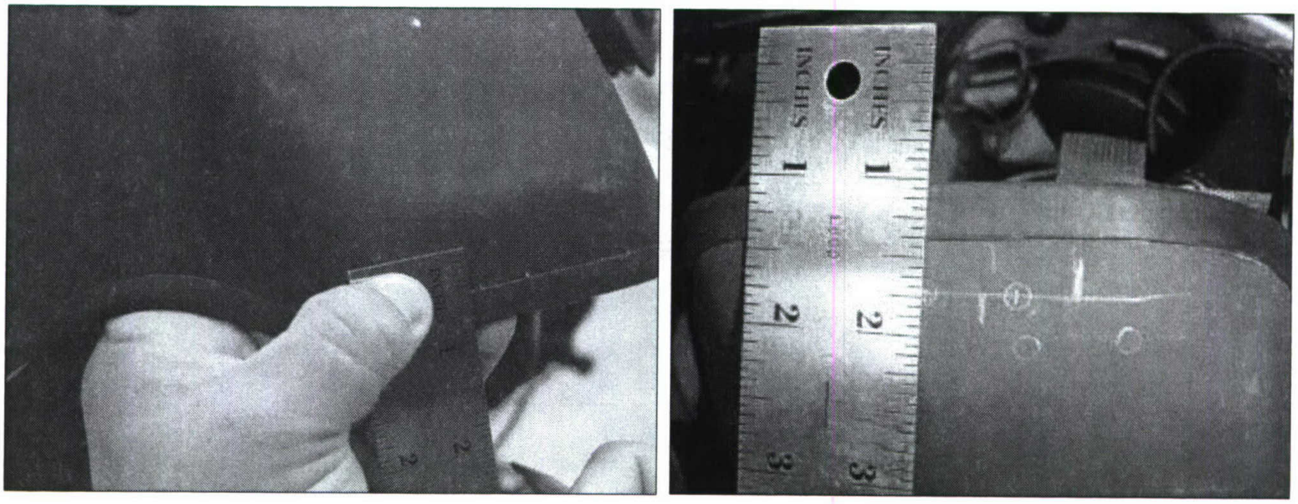

Figure 11. Two points being measured ¾ inches up from the edge of the right eardome.

4. Align the ¾-inch line on the template with the line drawn on the helmet (figure 12).

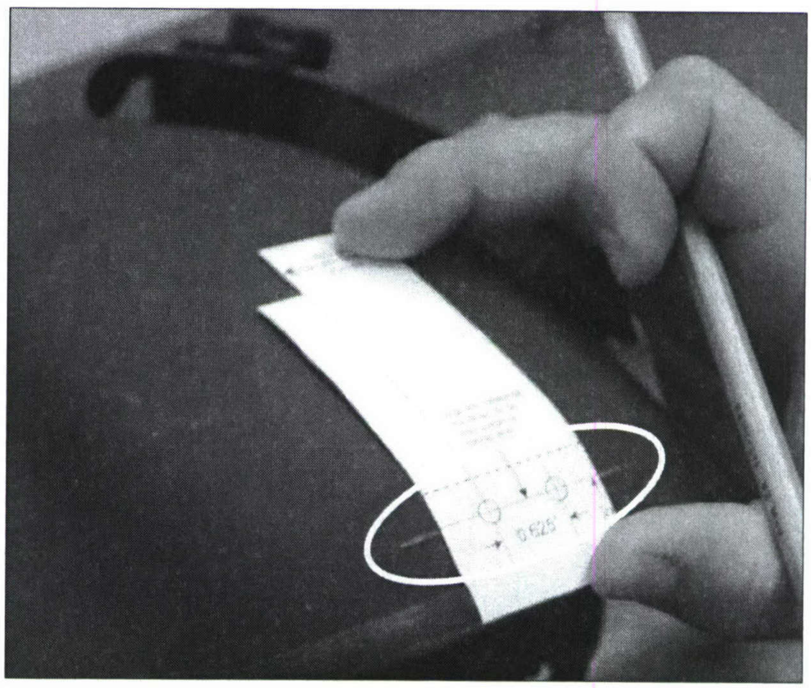

Figure 12. Vertical alignment of template on helmet eardome.

5. Align vertical edge of the template cut-out with the center of the dimple in the eardome (figure 13).

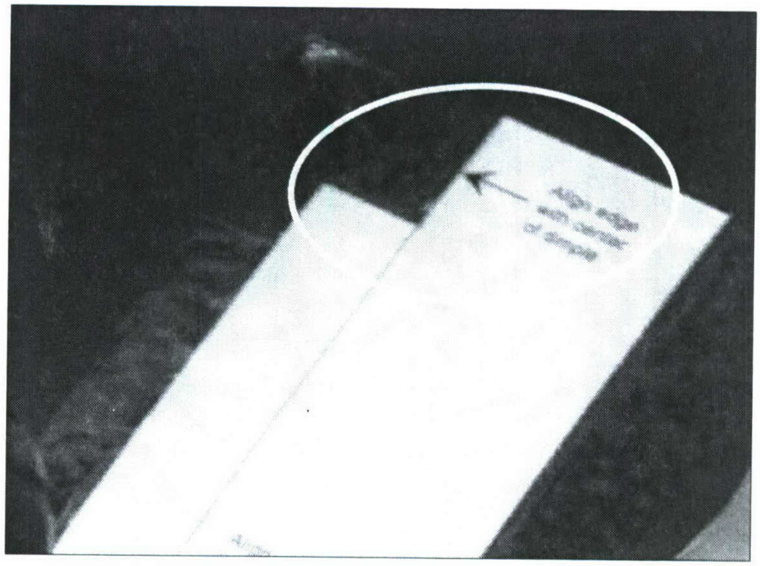

Figure 13. Horizontal alignment of template on helmet eardome.

6. Tape the template in place (figure 14).

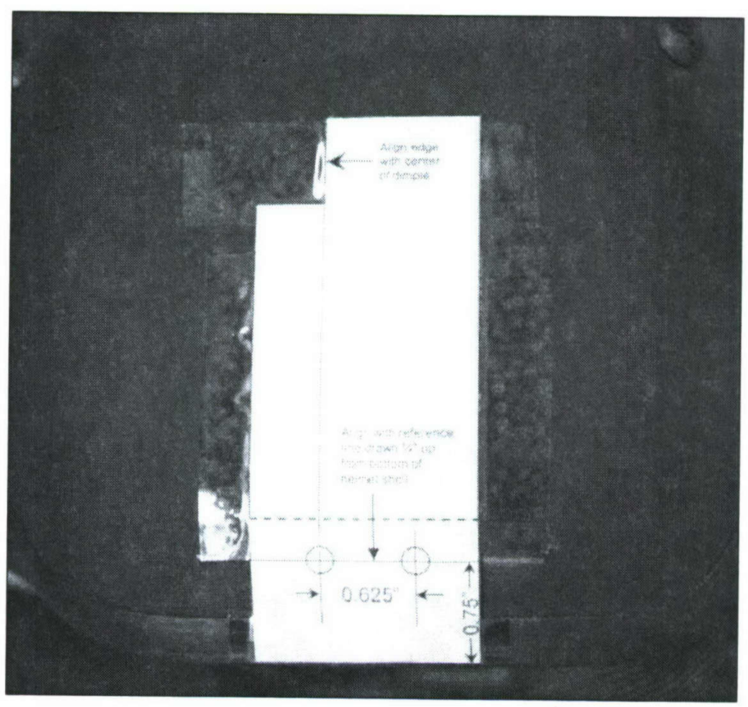

Figure 14. Template taped in place on eardome.

7. Drill the mounting holes: Start with a 1/16-inch bit to create two pilot holes, then expand the holes with a 9/64-inch bit, and finish with a 3/16-inch bit (figure 15).

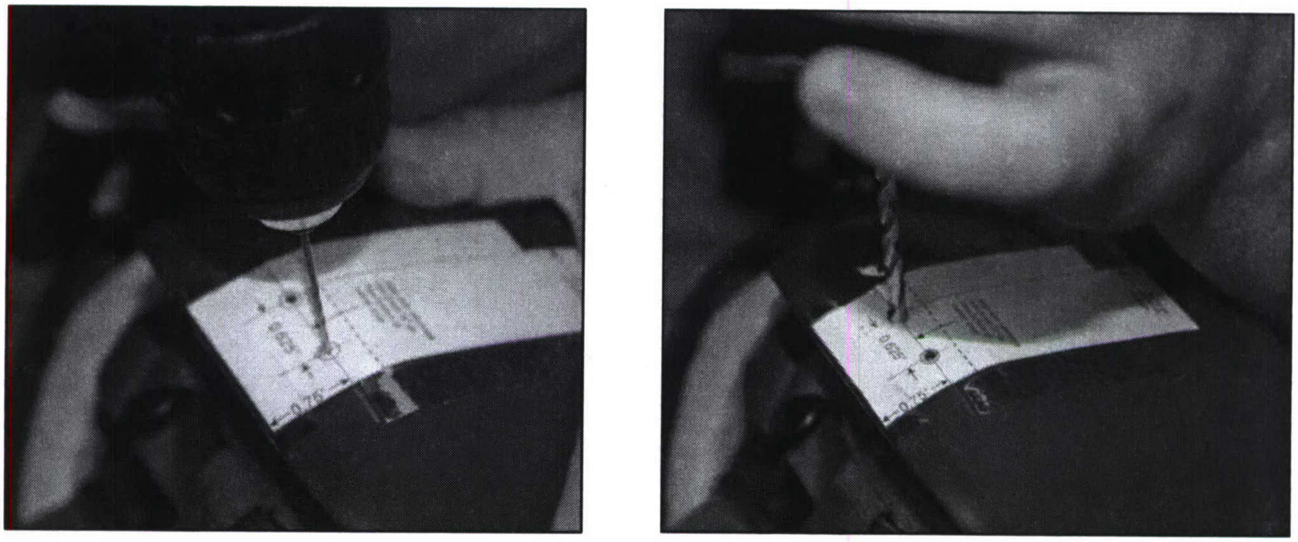

Figure 15. Mounting hole drilling locations.

8. Remove the template from the helmet (figure 16).

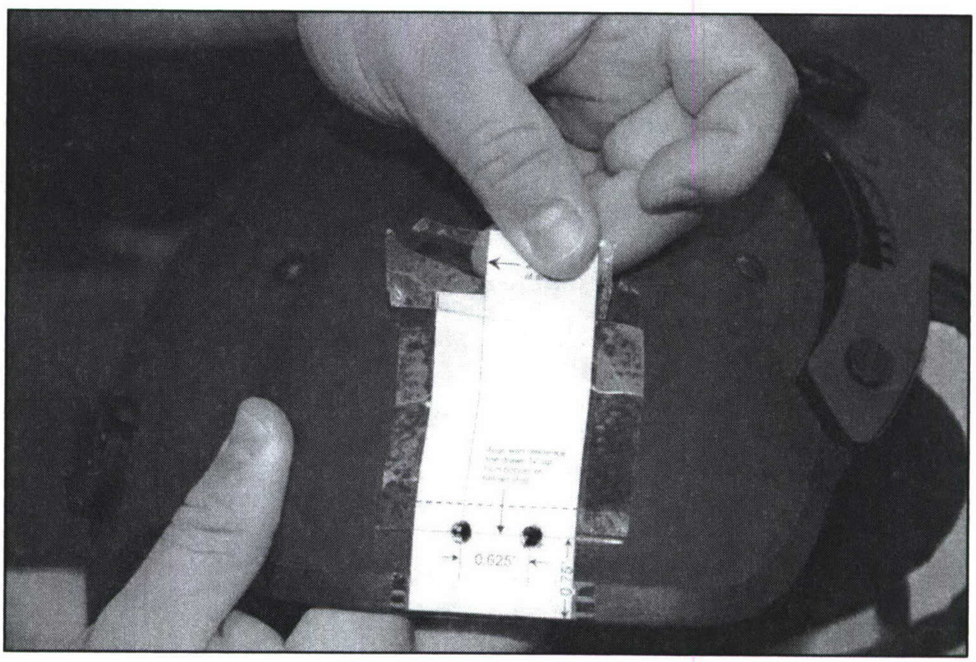

Figure 16. Template removal after drilling of cannula mounting holes.

9. Install the cannula (figure 17).

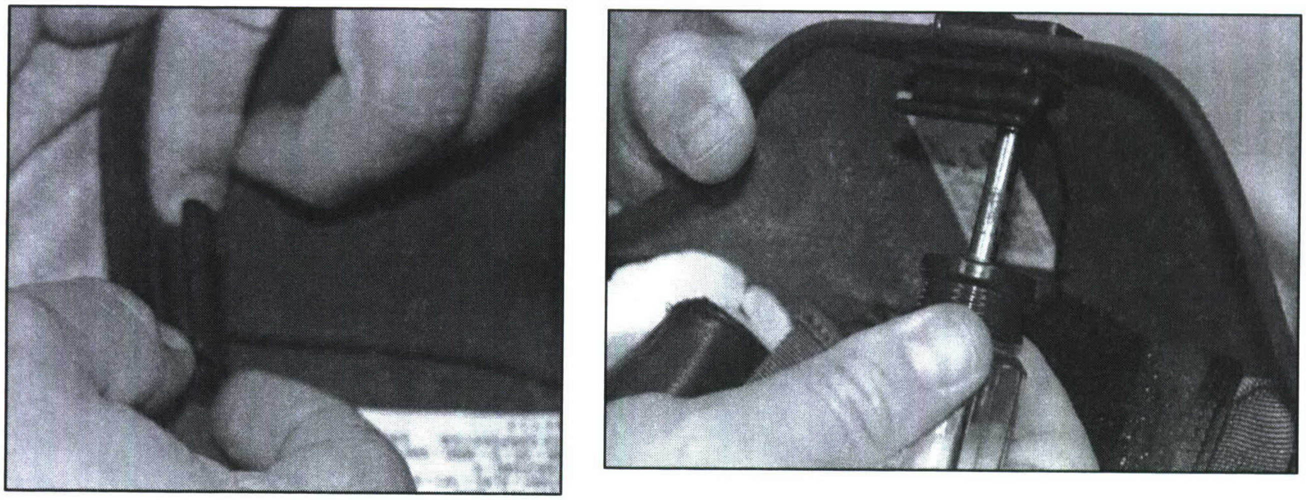

Figure 17. Cannula mounted on HGU-56/P.

10. If CEPS is installed on the helmet, use an adapter plate to route the wire clear of the cannula tube (figure 18).

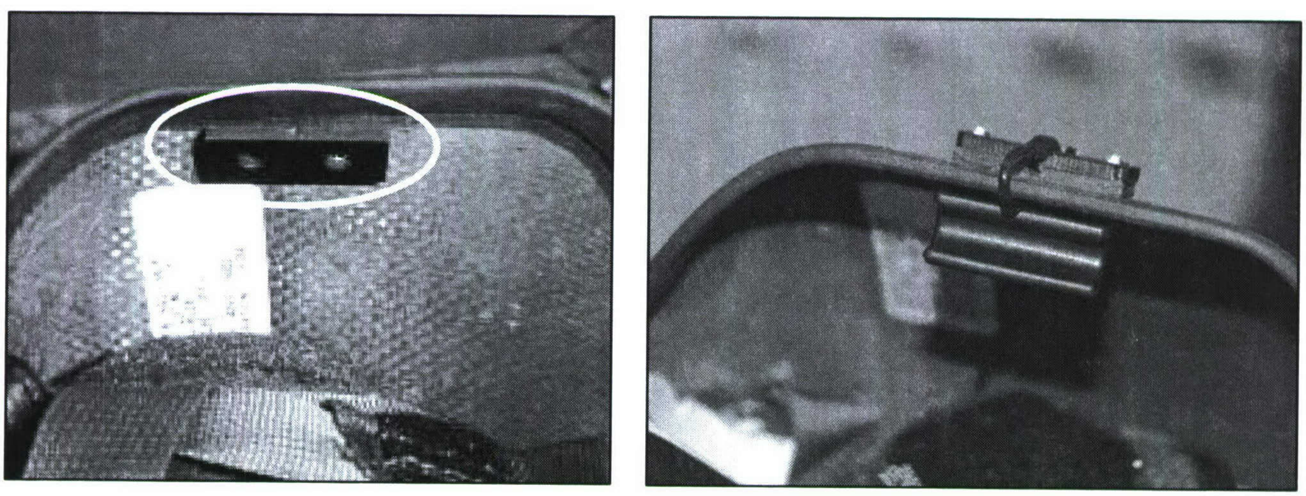

Figure 18. CEPS adapter plate used to route wire clear of cannula mount

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